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A Prototype UAV Control Station Interface For Automated Aerial Refueling

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Interim report for the period January 2005 to June 2005

June 2005

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This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

//Signed//

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14. ABSTRACT

The Air Force has recognized a growing need for an air refueling capability on Unmanned Air Vehicles (UAVs) as these programs have developed. Such a capability will allow the UAVs to deploy into theater, extend their combat range and add to their persistence in the battle area. The Air Force Research Laboratory's (AFRL's) Human Effectiveness Directorate, Warfighter Interface Division, System Control Interface Branch's (AFRL/HECI) Unmanned Combat Air Vehicle - Operator/Vehicle Interface (UCAV-OVI) Laboratory has developed prototype control station interfaces for controlling multiple unmanned air vehicles during the air refueling phase of flight. A simulation evaluation was initiated to allow various subject matter experts (SMEs) the opportunity to review and comment upon the features and preliminary design concepts of these display interfaces. As a baseline evaluation, the intent was to collect subjective data and determine if there were any major flaws with the design. The SMEs provided excellent comments and suggestions and there were no major obstacles to completing the air refueling task.

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PREFACE

This technical report was prepared in the Warfighter Interface Division, Human Effectiveness Directorate, of the Air Force Research Laboratory, Wright Patterson Air Force Base, Ohio. Mr. Gregory Feitshans was the Principal Investigator of this effort.

Members of the research team from General Dynamics were Robert Williams (subject matter expert) and Becky Singer (human factors).

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ACRONYMS

AAR	Automated Aerial Refueling
AFRL	Air Force Research Laboratory
ARCP	Air Refueling Contact Point
ARIP	Air Refueling Initial Point
ATC	Air Traffic Control
OTW	Out-the-Window
SME	Subject Matter Expert
TSD	Tactical Situation Display
UAV	Unmanned Air Vehicle

A PROTOTYPE UAV CONTROL STATION INTERFACE FOR AUTOMATED AERIAL REFUELING

INTRODUCTION

The Air Force has recognized a growing need for an air refueling capability on Unmanned Air Vehicles (UAVs) as these programs have developed. Such a capability will allow the UAVs to deploy into theater, extend their combat range and add to their persistence in the battle area. The Automated Aerial Refueling (AAR) program was initiated by the Air Force Research Laboratory's (AFRL's) Air Vehicles Directorate (AFRL/VA) to evaluate the feasibility of aerial refueling UAVs, including the exploration of workable concepts of operations that demonstrate how the technology might be employed in Air Force operations. In collaboration with VA's AAR program, AFRL's Human Effectiveness Directorate, Warfighter Interface Division, System Control Interface Branch (AFRL/HECI) developed prototype UAV operator display interfaces for the air refueling phase of flight through the Unmanned Combat Air Vehicle – Operator/Vehicle Interface (UCAV-OVI) program. A simulation evaluation was initiated to allow various subject matter experts (SMEs) the opportunity to review and comment upon the features and preliminary design concepts of these displays.

BACKGROUND

The UCAV-OVI program was initiated to develop effective operator display interfaces for unmanned vehicles by providing an advanced design, prototype, and test capability enabling quick look assessments. It is widely accepted that UAV systems will be highly automated, and that the operator's role will be one of a system manager or supervisory controller. As a system manager, the operator will be responsible for establishing system goals, monitoring and directing automated subsystems, and ensuring the overall success of the mission.

TECHNICAL APPROACH

The long-term Air Force "vision" is to refuel UAVs using techniques similar to manned aircraft refueling with minimal tanker fleet modifications. Therefore, it is important to understand that the term "automated" in AAR does not refer to any tanker or boom automation, but instead to the semi-autonomous algorithm on board one or multiple UAVs. The UAVs will receive high-level commands from the UAV operator, process sensor information, and generate corresponding lower-level trajectory commands for the UAV guidance, navigation and control system to achieve the operator command objective.

The AAR program performed functional and informational requirements analyses of UAV air refueling through the development of story boards of the operations concepts. The UCAV-OVI team then developed the UAV operator display interfaces using these information requirements in conjunction with Technical Order 1F-15E-1, Section VIII, *Air Refueling Procedures With KC-135 and KC-10*, as the references. A peacetime scenario environment was used to eliminate the issues associated with various emission control conditions during air refueling.

OBJECTIVES

Overall Objectives

The primary objective of this UCAV-OVI simulation evaluation was to *investigate control station display interface concepts and identify issues affecting the UAV operator to safely accomplish the air refueling task with a flight of four UAVs.*

Objective 1: Determine from potential UAV operators, the features of the current UCAV-OVI prototype air refueling concepts that are most useful.

Objective 2: Identify potential alternative display options and concepts thru discussions with potential UAV operators.

METHOD

Participants

Familiarity with the air refueling process was desired in this initial evaluation to ensure the participants would have a comparative baseline to provide the evaluators with viable comments concerning the UAV operator display interfaces. The seven participants included former F-16, F-18, F-111, KC-135 pilots; a former X-45A operator, and a former KC-135 boom operator.

Apparatus

The evaluation was conducted in AFRL's Aerospace Vehicles Technology Assessment and Simulation (AVTAS) laboratory. The operator-in-the-loop AAR simulation environment within AVTAS incorporated five main components to simulate the aerial refueling of up to four UAVs by a KC-135 tanker. The components included a simulation control console, a KC-135 boom operator station, a KC-135 pilot station, a simulation observer-referee station, and a UAV operator station. A detailed diagram of the overall environment can be seen in Figure 1. For this evaluation only the simulation control console and the UAV operator station were used.

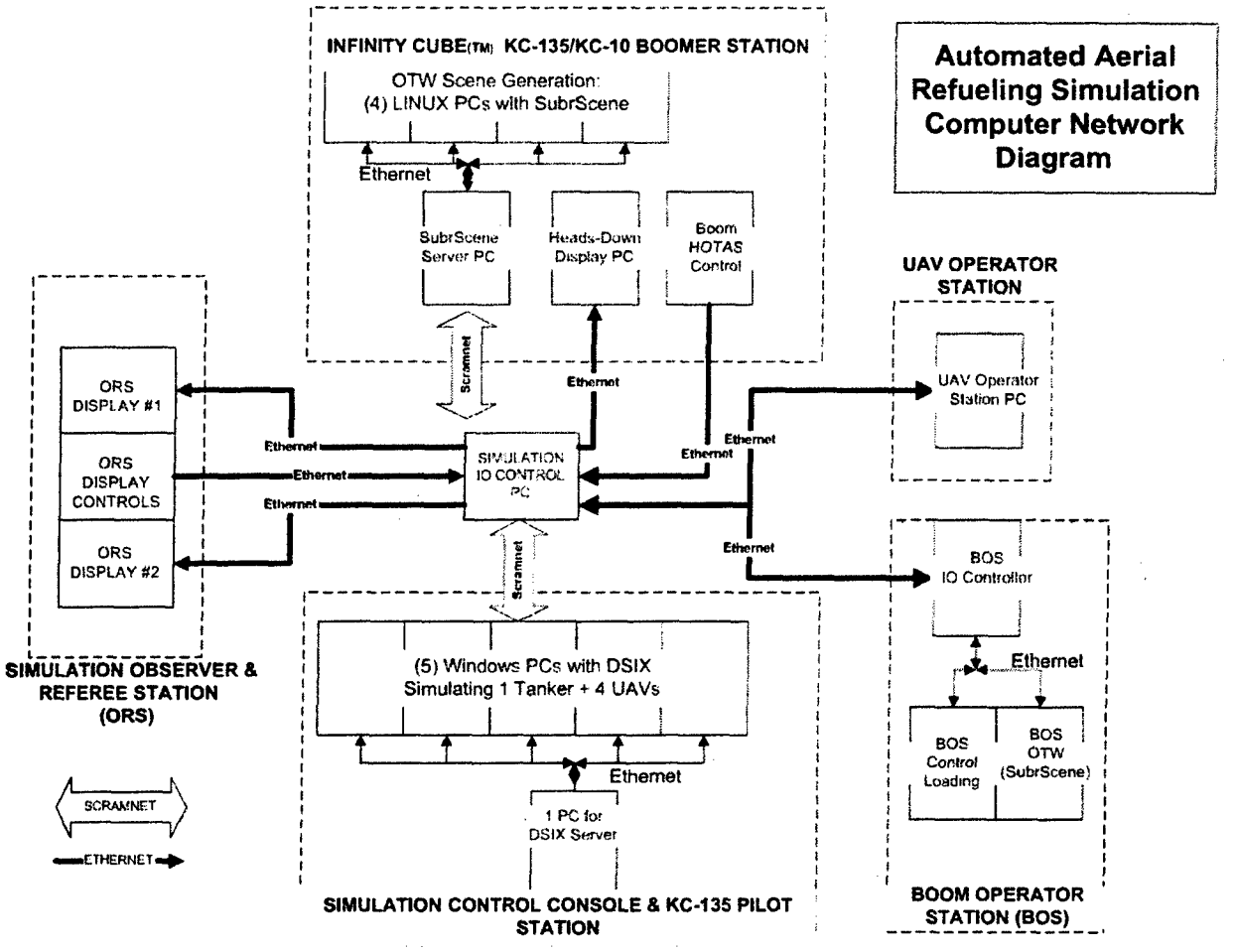

Figure 1. AAR Simulation Environment Structure.

Simulation Control Console

The AAR simulation operator supervised simulation execution from the simulation control console, shown in Figure 2. The console also served as the D-Six software development station containing all AAR-specific software hosted on six networked PCs. D-Six is a Windows-based simulation environment developed by Bihrle Applied Research. The AAR D-Six environment consisted of four PCs, each running a distinct, high-fidelity UAV and onboard AAR algorithm model, one PC running a medium-fidelity KC-135 tanker model including a boom model, and a sixth PC running a D-Six specific network server. The console computer hardware consisted of two 1 GHz, Pentium III PCs with 1 GB of RAM and three 2.4 GHz, Pentium 4 PCs with 512 MB of RAM all running under the Windows 2000 operating system. More PCs could be added to the D-Six computing network as modeling complexity or number of simulated aircraft increases.

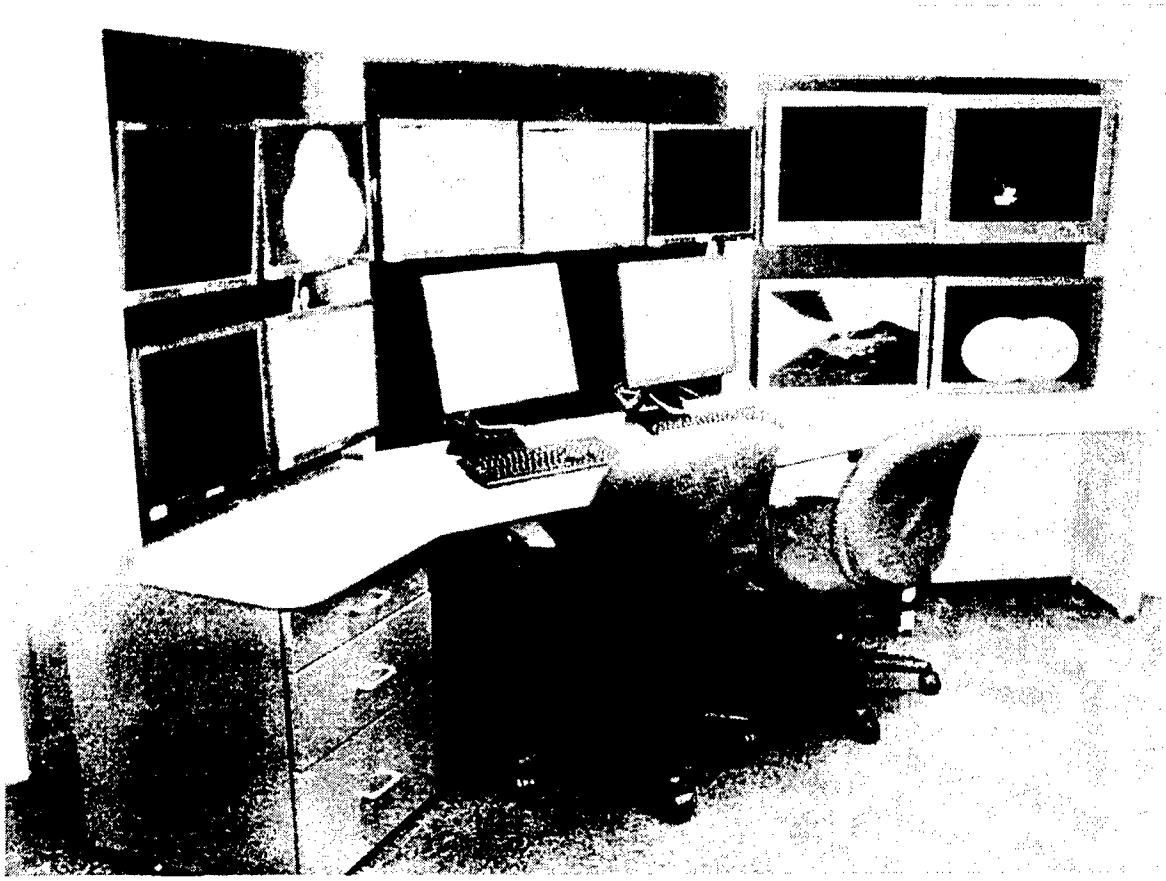

Figure 2. Simulation Control Console

UAV Operator Station

The UAV operator station, developed by the UCAV-OVI team, simulated a remote operating station allowing a single operator to control a flight of up to four UAVs. The UAV operator sent commands from the station to the UAVs, and the commands were interpreted by the autonomous AAR algorithm operating within the D-Six model. This algorithm guided the UAVs to the commanded positions in the AAR formation.

The station's computer hardware consisted of a dual 3.06 GHz, Pentium IV PC with 2 GB of RAM and a NVIDIA Quadro Fx 3000 video card running under Windows XP SP2. The display interfaces were depicted on two side by side computer monitors (Figure 3) with keyboard and mouse inputs. The right monitor was configured showing a 3-D virtual environment depicting the KC-135 and UAV positioning, a tactical situation display with mapping under lays for an overall situational awareness, and finally, a status page depicting the UAV fuel tanks. The left monitor was the primary display for the air

refueling. It was configured with the Air Refueling control display centered on the KC-135 and showed the UAVs in their allowable commanded positions as well as the operator controls to manage the UAVs during the air refueling.

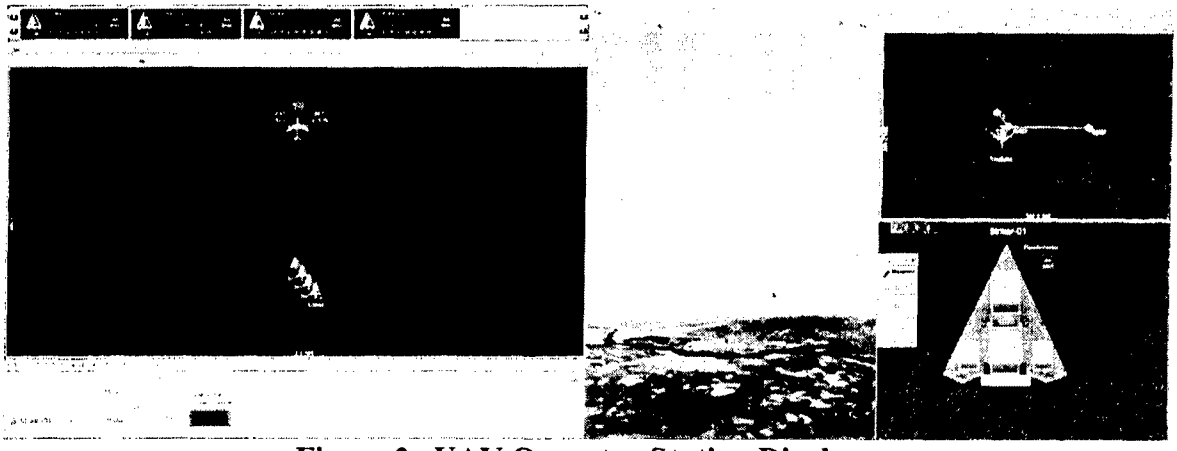

Figure 3. UAV Operator Station Displays

The software consisted of an adjustable-scale moving map showing UAV positioning relative to the tanker, and a small-scale display centered on the KC-135 which allowed the operator to command the UAVs positions through the aerial refueling process. The UCAV-OVI simulation software was constructed using Microsoft Visual Studio, third party component libraries, and the OpenGL graphics libraries. Industry standard software interface concepts were utilized whenever possible so that operators were familiar with most interface techniques.

Right Monitor

The right monitor's display interfaces (Figure 4) primarily gave the operator situational awareness. It was not used to manage the UAVs in flight. The three display interfaces consisted of: the Tactical Situation Display (TSD), the Fuel System display, and the Out-the-Window (OTW) display.

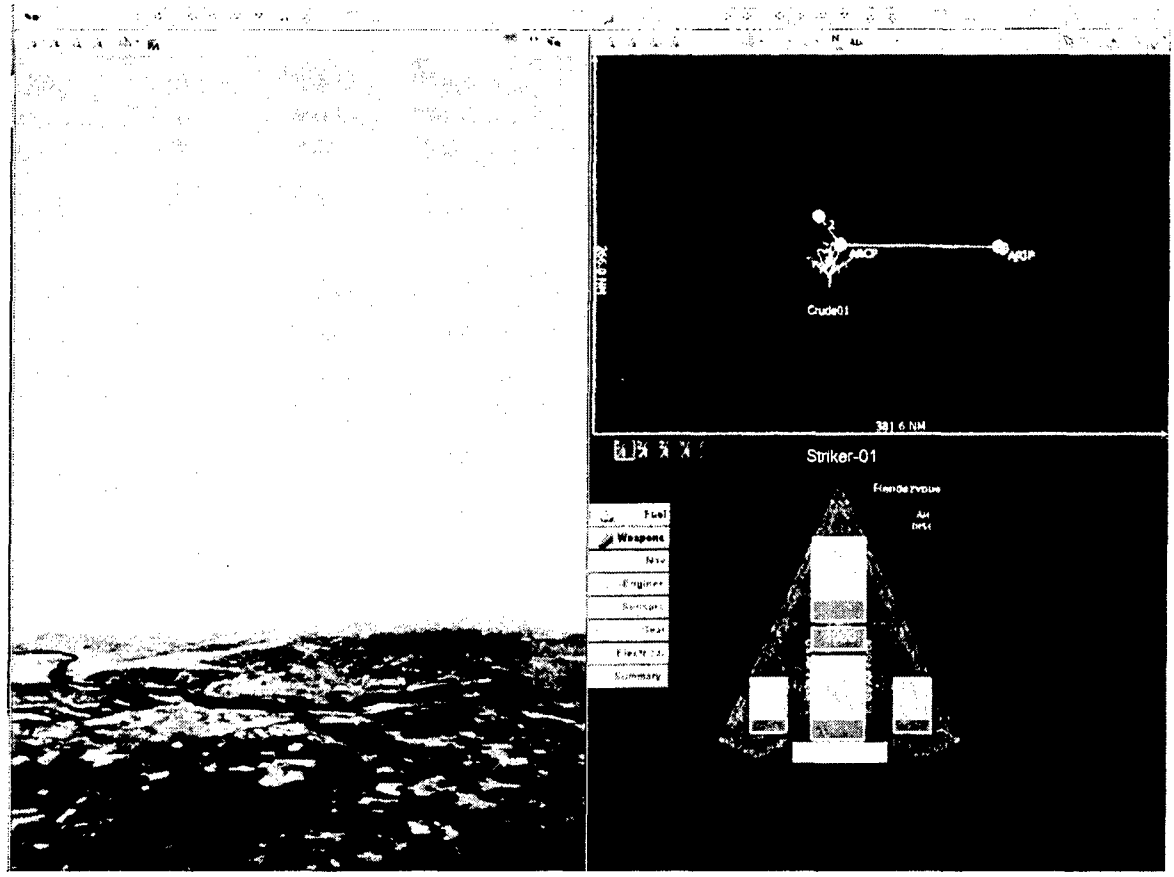

Figure 4. Right Monitor Display Interfaces

Tactical Situation Display

The tactical situation display interface (Figure 5) consisted of digitized pilotage maps showing the planned route of flight of the UAVs and the positions of the UAVs as well as the tanker. The operator could zoom and pan the TSD as well as select various types of maps. Scales were shown on the horizontal and vertical axes giving distance in nautical miles.

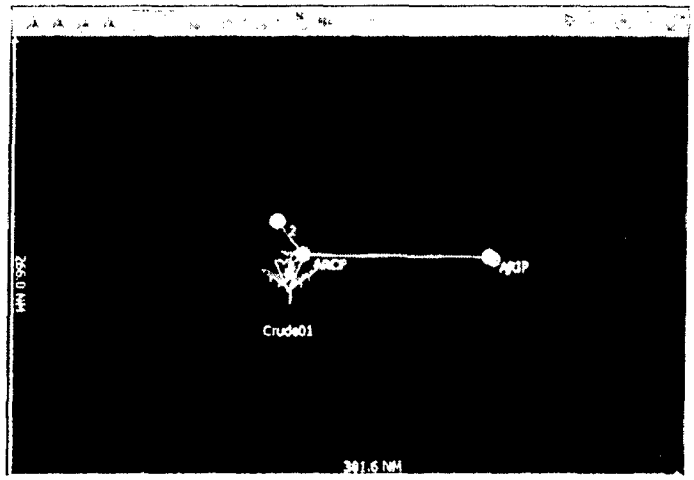

Figure 5. Tactical Situation Display

Fuel System Display

The Fuel System display (Figure 6) showed the total quantity and individual fuel tank quantities for the selected UAV. The operator selected the UAV of interest on this display using the vehicle selection buttons in the upper left of the window.

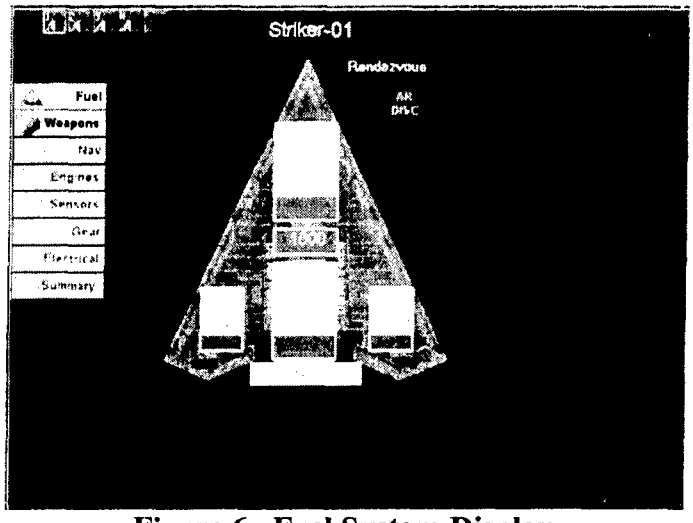

Figure 6. Fuel System Display

The Out-The-Window Display

The Out-the-Window display (Figure 7) was a virtual display depicting the positional information of the UAVs and tanker. There were two operator selectable views used in the simulation to enhance situation awareness. The head up display gave the operator an out the nose virtual view from the selected UAV. The orbital view was used to give a

detached perspective of the selected UAV. This view could be zoomed in or out from the UAV using the mouse wheel. It could also be moved in azimuth around the UAV using the right mouse button and moved in elevation using the left mouse button. The orbital view gave an enhanced situational awareness about the UAV and the surrounding UAVs, as well as the tanker.

Figure 7. Out-The-Window Display

Left Monitor

The left monitor (Figure 8) contained the main command and control display interfaces for the operator to manage the UAVs during air refueling. The display consisted of three distinct control and monitoring mechanisms; the summary panels, the graphical refueling display; and the command window.

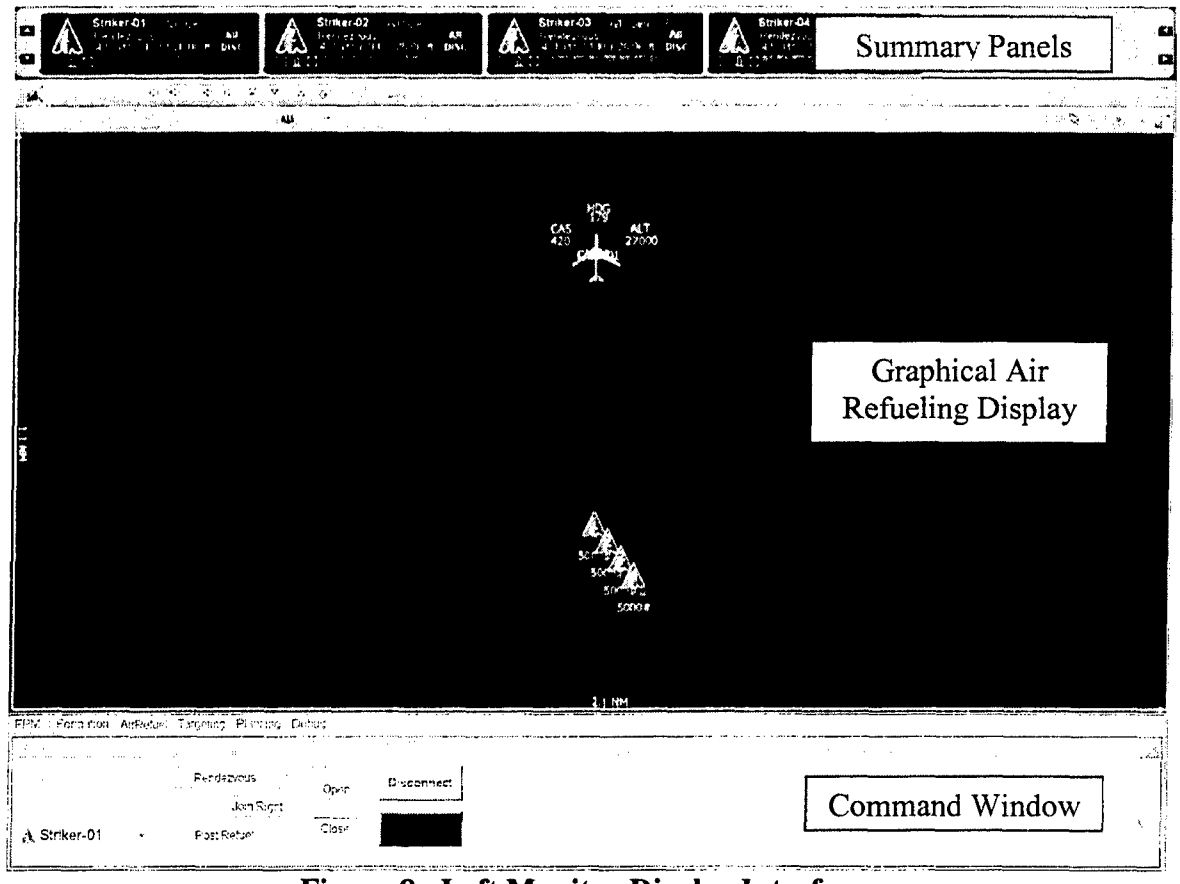

Figure 8. Left Monitor Display Interfaces

Summary Panels

Across the top of the display are the Summary Panels (Figure 9), one for each of the UAVs. The summary panels give the operator a quick view of the status of each of the UAVs.

Figure 9. Summary Panels

Graphical Air Refueling Display

This display interface gave position information about the UAVs, tanker, commanded positions. It was the primary mechanism for commanding the UAVs during the air refueling process.

Commanded Positions

The UAVs could be commanded to fly to several predefined positions about the tanker (green chevrons). These included the observation, post refueling, precontact, and contact positions (Figure 10). Once a UAV was commanded to a particular position, a magenta outline of the UAV was shown at the appropriate position. The operator would accomplish this by selecting a UAV and either left mouse click on the desired commanded position chevron or hold the left mouse button and drag a tether to that position. The command would then be sent and to the UAV immediately, and the UAV would begin flying toward the position. (The double green chevrons on the tanker's nose denote the tanker is the flight leader).

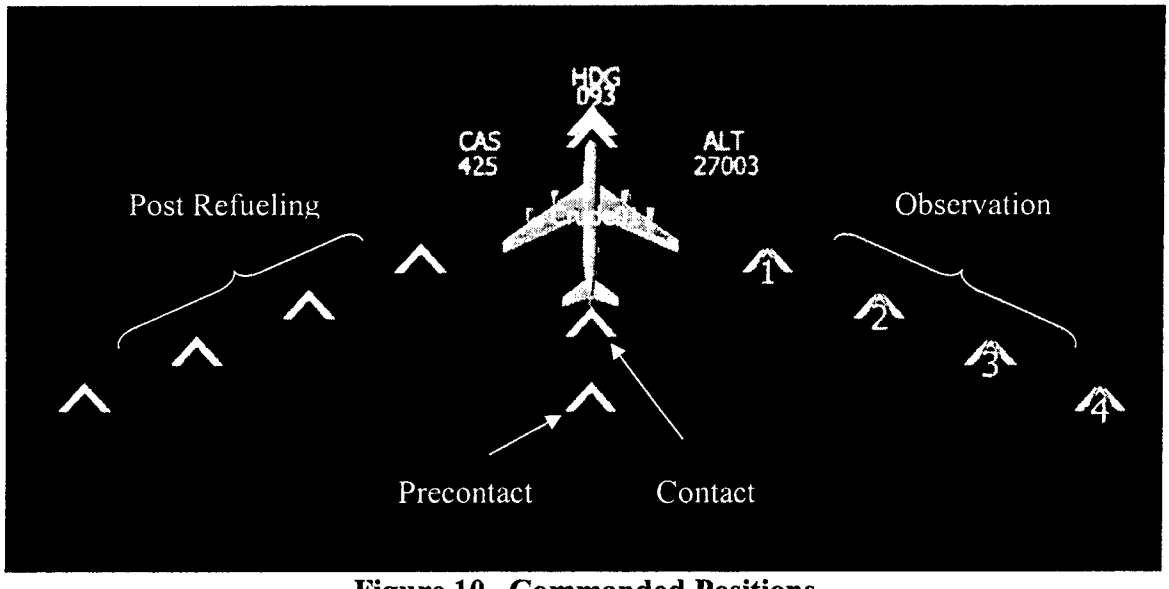

Figure 10. Commanded Positions

UAV Icon Air Refueling System Status

The UAV icons had three lights corresponding to the air refueling system status (derived from the F-16) (Figure 11). The lights were blue for ready (RDY), green to show contact with the boom (AR), and yellow to show the boom disconnect (DISC). The total fuel quantity of each UAV was shown below these three lights.

Figure 11. UAV Air Refueling System Status Lights

Command Window

The command window provided a series of list boxes that allowed the operator to select from various UAV flights (if multiple flights were available) as well as which tanker to engage for the air refueling (Figure 12). To select an individual UAV in the command window the operator would utilize the drop-down list box containing each UAV in the selected flight. Once selected, the operator could open or close the refueling door of the UAV using those respective buttons. There are also the rendezvous and join up buttons to command the UAVs to engage the appropriate algorithms allowing the UAV to fly to the predetermined formation positions relative to the tanker. The operator can select which UAV to work with using the Call Sign drop down list. The Disconnect button released the air refueling boom for the selected UAV, and the Breakaway button was used for emergencies. Lastly, post refuel button commanded the UAV flight to descend 1000 feet below the tanker while awaiting ATC clearance out of the air refueling airspace.

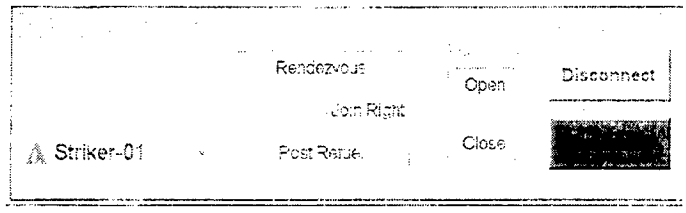

Figure 12. Command Window

Procedures

Introduction and Training.

Participants were given a general introductory briefing that provided the context and purpose of the evaluation, including scenario description and tasks to be performed. A detailed description of each of the UAV controls and display features were provided as well as their context of use. Given that the primary source of evaluation data was to be in the form of participant comments and opinions, responses and comments made during this discussion were noted and incorporated into the overall data collection protocol.

UAV Air Refueling Scenario

Four UAVs, call signs Striker 01 through Striker 04, were scheduled to air refuel with a KC-135 tanker, call sign Crude 01. The air refueling was accomplished using point parallel rendezvous procedures on a published air refueling track with UHF radios for communications (peacetime training procedures). Crude 01 was holding at the Air Refueling Contact Point (ARCP) at 27,000 feet MSL and 275 knots. Approaching the Air Refueling Initial Point (ARIP), the UAV operator received permission to enter the air refueling airspace from air traffic control (ATC). The UAV operator changed the UHF radio frequency to the air refueling frequency and informed Crude 01 the UAVs were enroute to the ARIP. The UAV operator notified Crude 01 when the UAVs crossed the ARIP. At that time Crude 01 turned toward the ARIP and the UAVs proceeded towards the tanker at 26,000 feet and 300 knots.

When the tanker was 26 degrees and 21 nautical miles from the UAVs (per Technical Order 1F-15E-1), the formation join-up of the tanker and UAVs began. The UAVs flew to a position one nautical mile aft of and 1,000 feet below the tanker. They continued the

join up on the tanker until they were at the predefined observation positions on the tanker's right wing (Figure 13).

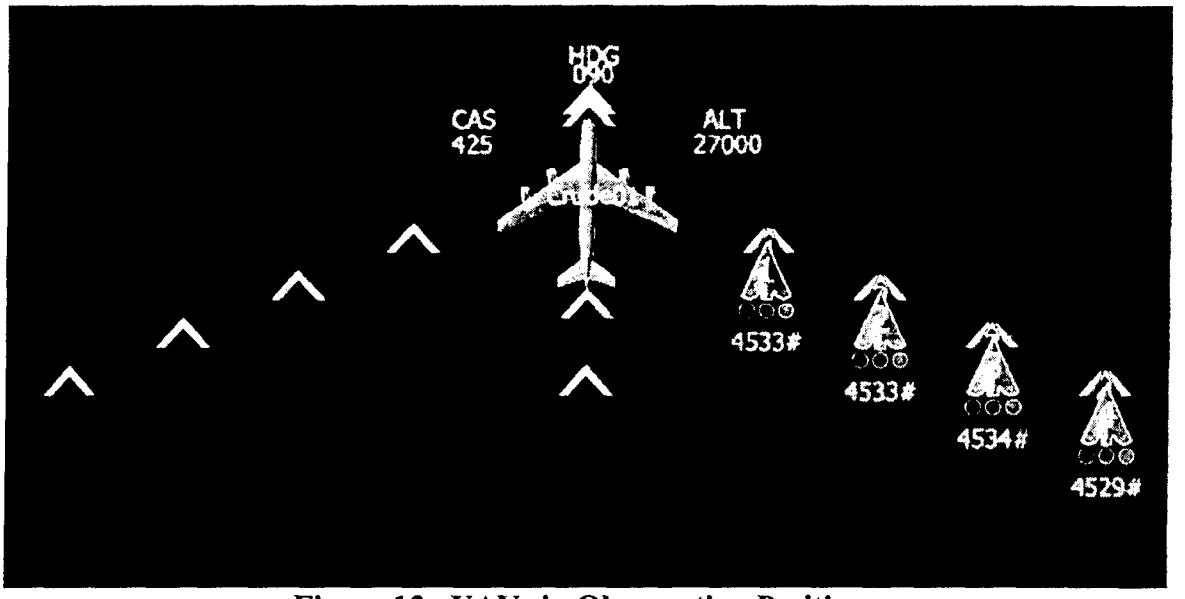

Figure 13. UAVs in Observation Positions

Once the UAVs were positioned at the observation positions, the UAV operator received permission from the boom operator to move (using the mouse to drag the selected first UAV, Striker 01) to the precontact position (Figure 14). While Striker 01 was transitioning to the precontact position the UAV operator configured Striker 01's systems for refueling (open the air refueling receptacle, turn off the rotating beacon, etc.). The RDY, AR, and DISC lights were displayed below the UAV (with the RDY light on) denoting the UAV was ready for air refueling. Once Striker 01 was established at the precontact position, the remainder of the UAV flight transitioned to the vacated observation position. After receiving permission from the boomer, the UAV operator moved Striker 01 to the contact position (Figure 15). The boomer positioned the boom in the receptacle and the UAV received fuel (denoted by the AR light on).

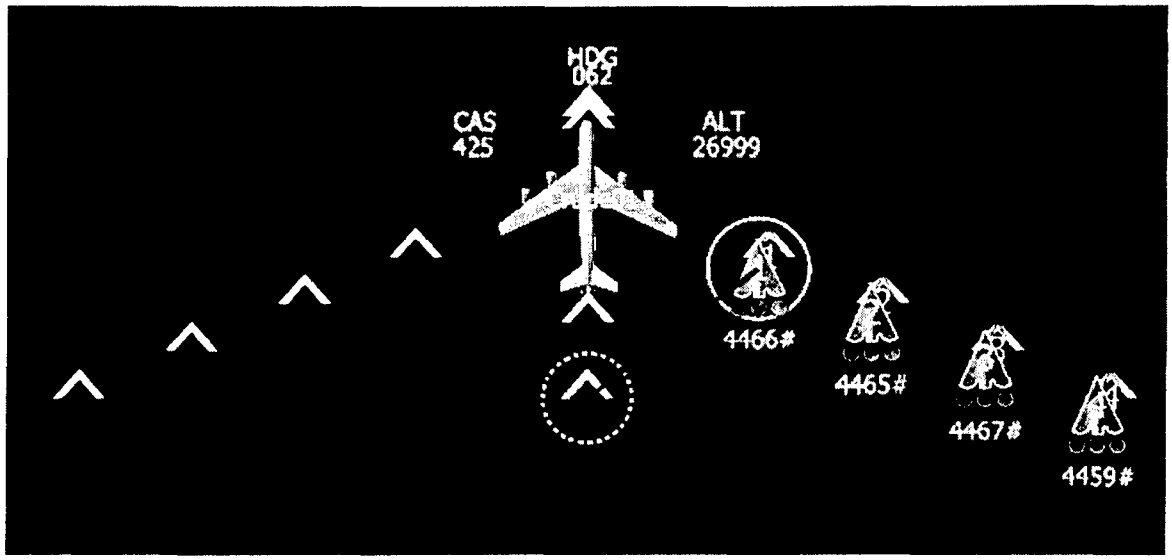

Figure 14. Commanded to Precontact Position

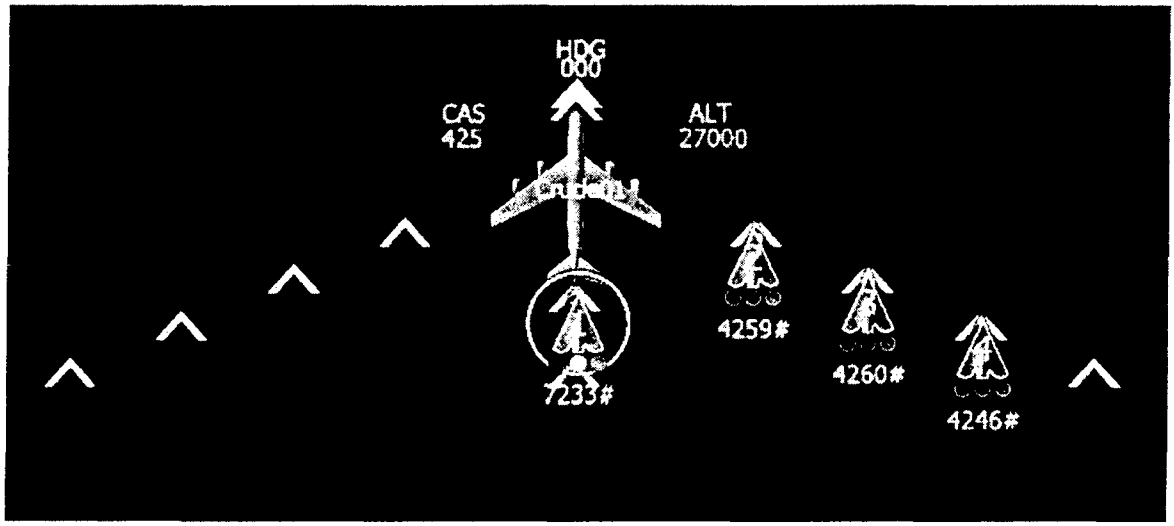

Figure 15. Contact Position

After the scheduled amount of fuel was transferred, the boomer disconnected the boom (denoted by the DISC light on). The UAV operator then moved Striker 01 back to the precontact position, closed the air refueling receptacle. From the precontact position the operator moved the UAV to the post refueling position (Figure 16). This sequence was repeated until the four UAVs completed the air refueling.

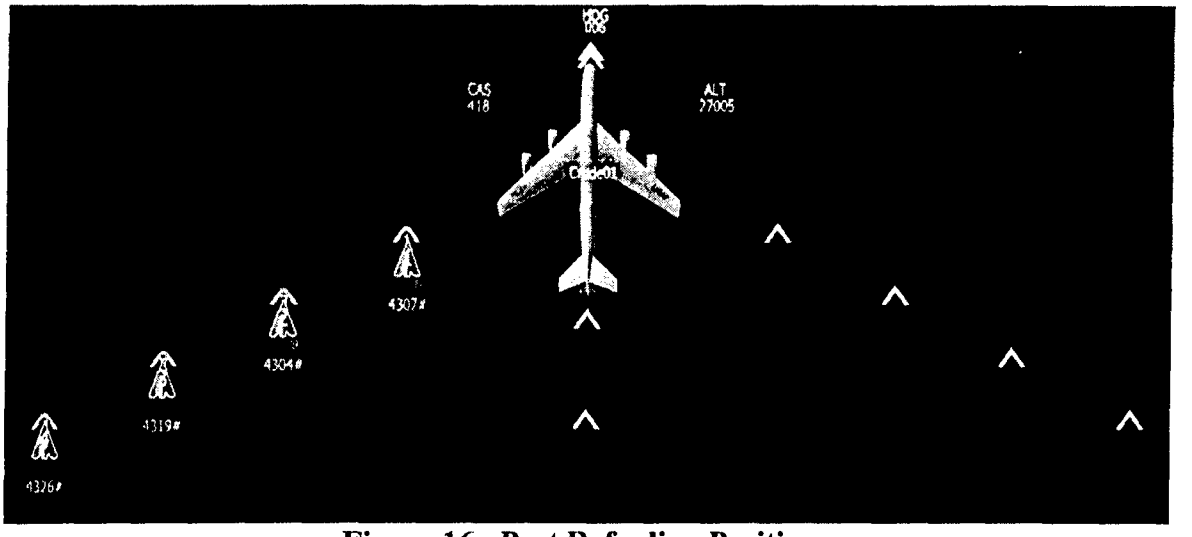

Figure 16. Post Refueling Positions

The UAV operator began the post refueling procedure by descending the UAVs to the bottom of the air refueling altitude block (using the post refuel button) while asking Crude 01 for the post refueling report and the ATC clearance. Once the ATC clearance was received, the UAV operator contacted ATC on the assigned UHF radio frequency and received permission to leave the air refueling airspace. At that point the air refueling phase of flight was completed.

DISCUSSION

The primary objective of this evaluation was to obtain feedback from subject-matter experts (SMEs) regarding the UAV operator's control display interfaces and identify issues associated with accomplishing the air refueling phase of flight. The SMEs were asked to provide candid comments on all aspects of the display interfaces and processes as they were performing the simulation. Following completion of the evaluation, they were asked to complete a survey and provide additional comments. The surveys and comments are in the appendices.

Overall, the display interfaces were very well received by all SMEs and in all cases the air refueling process was completed with no major obstacles. However, based on operator feedback, there are several areas where modifications to the display interfaces and the process could provide significant improvement. The most recurring comment the

participants made was regarding ***overlapping icons*** on the primary display (Figure 17). As the UAVs flew into the commanded positions, overlap occurred with the commanded position icon (the chevron and the magenta UAV outline) and the UAV icon. To move a UAV, the operator must select the UAV icon and either drag it to the desired position or mouse click in the desired position. However, attempts to do this were often not successful because the operator thought the intended icon was selected when in fact the previously selected icon was still active, causing the incorrect UAV to be moved. A drop down list of the overlapping icons was implemented in the simulation to aid the selection process; however, the participants frequently did not use it. A possible suggested solution was to make the magenta outline less similar in shape than the UAV icon, perhaps using a plain triangle rather than an outline of the vehicle. Still another possible solution would be allowing only the dragging method to move the UAVs, since the magenta outlines are not selectable. This would eliminate the confusion of which UAV was being moved.

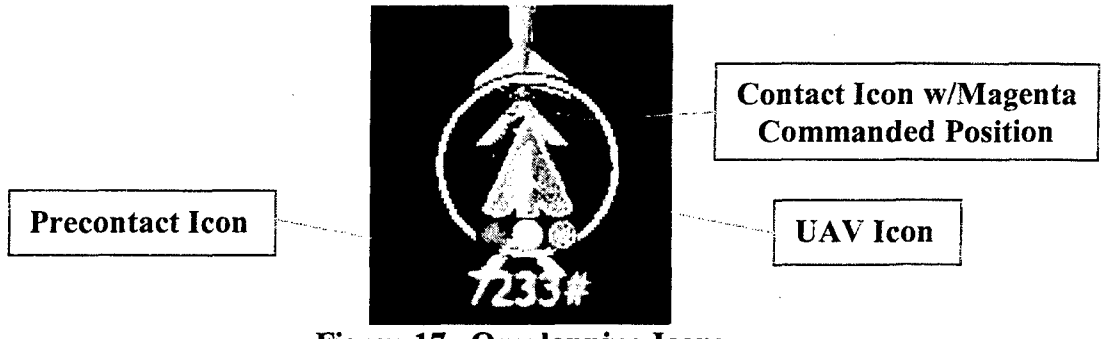

Figure 17. Overlapping Icons

The second most recurring comment by the participants was ***lack of error notices or feedback*** for incorrect movements. For instance, operators were able to move the UAVs to positions that were not logical, such as moving a UAV to the precontact position while another UAV was still in the contact position. Other illogical moves were also possible, prompting participants to suggest having a message or alert (aural or visual) to indicate that a particular move was not allowed.

A third recurring comment was the ***addition of chevrons and magenta UAV outline*** to indicate the commanded position for the UAV during a "breakaway". When this command is issued, the UAV icon pulls back from the tanker and retreats to an unseen

position. The participants would like to know where the UAV is going, either by the use of the chevron or by providing a magenta tether, connecting the UAV to the breakaway position.

A final recurring comment was to provide more ***automation*** for the UAV being refueled. When a UAV is selected to be moved to the precontact position, the operator must select "open door" in the lower left command box and when the refueling is complete, must select "close door" in the command box. A possible solution is to automate the fuel door to open and close when moving to or from the precontact position. In addition, automatically updating the Fuel System Display on the right monitor to reflect the UAV being refueled would allow the operator to instantly see the fuel tank quantities without having to move the mouse cursor to the right monitor and select the UAV of interest.

There were other comments that are worthy of mentioning. Several participants expressed concern over being able to quickly move to the breakaway button if an emergency situation were to arise. Suggestions included adding a voice command option or perhaps using a physical switch, such as a foot switch so that the operator would not have to quickly locate the mouse cursor to move to the command buttons. Another suggestion was to place the breakaway and disconnect buttons on both the left and right monitors allowing faster selection.

The survey administered following the task yielded favorable responses overall. The questions yielding the highest ratings (4.6 out of 5) queried the participants to rate the effectiveness of the positioning chevrons and the realism of the Out-The-Window display. These ratings are consistent with comments noted during the evaluation sessions in which participants commented on the utility of the chevrons in seeing the position of the UAV and possibly adding an additional chevron for breakaway positioning. One participant suggested providing feedback to indicate when the UAV has reached the intended position. The Out-The-Window display received positive comments from all of the participants and was used frequently to obtain various viewpoints of the UAVs and increase situation awareness.

The lowest average rating on the questionnaire (3.1 out of 5) resulted from the question seeking feedback on whether the UAV could be selected and positioned quickly and accurately. Again, this rating was consistent with comments noted during the evaluation and from observing the participants attempts to move the UAVs. See the Appendices for complete comments.

SUMMARY

The goal of this evaluation was to obtain subject-matter expert feedback on the display interfaces and the functionality of the air refueling process. As a baseline evaluation, the intent was to collect subjective data and determine if there were any major flaws with the design, not to measure participant performance. As was hoped, the SMEs provided excellent comments and suggestions and there were no major obstacles completing the task.

As discussed above, there were four issues that were agreed upon by all of the participants. The recurring issues were: the overlapping icons; the lack of error notices and feedback for incorrect movements; adding a chevron for the breakaway maneuver; and the addition of more automation to the process to eliminate what was considered to be trivial steps. The consensus of the participants indicated the need to address these items which would result in the necessary information and situation awareness for the UAV operator to successfully complete the air refueling task.

APPENDIX A

Data Collection and Questionnaires

Two sources of data were sought for this initial evaluation: opinions and comments from the participants as they were performing the air refueling task, and feedback from a written questionnaire following the task. The questionnaire consisted of nineteen structured questions and three open-ended questions. The structured questions fell into four categories: Navigation, Display Content (for left and right monitors), and Terminology. These were rated on a five point scale consisting of Strongly Disagree (1), Disagree (2), Neutral (3), Agree (4), and Strongly Agree (5). Space was provided for additional comments for each question. The open-ended questions sought feedback for changes to improve the scenario, recommended requirements, and any aspects of the displays that were not liked. The nineteen structured questions were formatted as follows:

1. The sequence of steps required to complete the AAR task is logical, clear and efficient.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

Comments:

In addition, the following background information was collected for each subject (the profiles can be seen in Appendix B):

Background information:

Name (not to be publicly disclosed):_____

Years of air refueling experience: _____

Type of aircraft(s) flown: _____

Number of hours flown (per aircraft):_____

Results

The results presented below (Questions 1-19) include the actual responses by the participant, the percentage of participants that responded to a particular category, and any additional comments that were added. The Open-ended questions (#20-22) contain only comments from the participants, however several participants felt they expressed themselves sufficiently in the comments section of the structured questions and opted to skip these questions. The "Subject's Comments" section is a compilation of notes taken by the observers of the participant's comments as they were performing the air refueling task.

1. The sequence of steps required to complete the AAR task is logical clear and efficient.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
	0%	14%	0%	43%	43%
S1				X	
S2				X	
S3				X	
S4		X			
S5					X
S6					X
S7					X

Subject	Comments
2	Would like right display to always default to UAV of interest or one controlling.
4	Moving the ships around is logical and clear. The process is not efficient. Automating by adding a "cycle" button with pre-programmed cycle logic would make it "efficient". Also, entire process can be automated except join-up, begin AAR, breakaway.
7	Just for SA, might want to add an A/R checklist that shows what steps have been accomplished/need to be accomplished.

2. The display content provided is sufficient for successfully performing the AAR.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
	0%	14%	0%	43%	43%
S1					X
S2				X	
S3		X			
S4				X	
S5					X
S6				X	
S7					X

Subject	Comments
1	I really like the OTW display. I would suggest enabling perspective slewing. Look up and down from right mouse button, and head position from left button.
2	Would like to see "green chevron" and magenta ghost for Disconnect and Breakaway positions. Would like auto zoom in/out to keep UAV of interest in sight.
4	Chevrons are good reference, manipulating aircraft is cumbersome.

hile navigating between the left monitor and right monitor.

3. The cursor is easy to locate w

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
	0%	0%	0%	86%	14%
4. The procedures for moving th				X	
				X	
S2				X	
S3				X	
S4					X
S5				X	
S6				X	
S7					

Subject	Comments
1	It would be good to highlig ht the active display or to make it active automatically when the cursor is over it.
7	May investigate possibility of providing options for the mouse cursor (ala Windows). For instance, enabling a trail, fl ashing cursor, larger cursor, etc.

ıe UAVs are logical, clear and efficient.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
	0%	14%	0%	86%	0%
S1				X	
S2				X	
S3				X	
S4		X			
S5				X	
S6				X	
S7				X	

Subject	Comments
1	Several times when I attempted to select an airplane to move it, I selected its current slot instead. Then when I selected the next slot, another airplane (the last one selected) would go there.
2	Some confusion on which UAV was "grabbed". Sometimes I thought I "grabbed" a new UAV but actually grabbed the position.
4	See comment #1
5	Overlapping icons are distracting.

5. Selecting the desired UAV icon for positioning can be done quickly and with accuracy.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
	0%	29%	29%	43%	0%
	selected incorrectly.				
S2			X		
S3		X			
S4			X		
S5				X	
S6				X	
S7				X	

Subject	Comments
1	See comment on question #4. It might be better to prevent selection or a slot if a UAV is occupying it.
2	See #4 comment.
3	The display overlaps selection and command. The drop down menu ended up being my primary mode of aircraft selection and command
4	If you click too quickly, you can get in a situation where the aircraft are being manipulated or
5	See #4 comment.

6. The "RDY", "AR" and "DISC" lights situated under each UAV were unambiguous and clearly seen.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
	0%	0%	0%	57%	43%
S1				X	
S2				X	
S3					X
S4				X	
S5					X
S6				X	
S7					X

Subject	Comments
4	No issues, had some difficulty in getting them to engage, but when it was functioning it worked well

7. The command movement outlines (magenta outlines) are logical and useful.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
	0%	0%	29%	14%	57%
S1				X	
S2					X
S3			X		
S4			X		
S5					X
S6					X
S7					X

Subject	Comments
2	Loved the magenta outlines - could see where I sent the UAV. Would like to see them for disconnects and breakaways also. -

8. The positioning chevrons are effective and useful

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
	0%	0%	14%	14%	71%
S1				X	
S2					X
S3					X
S4			X		
S5					X
S6					X
S7					X

Subject	Comments
2	Would like to see these for the disconnect and breakaway.
3	I like these. You need some feedback on when the aircraft considers these positions to be achieved
4	See comment #2
5	Need a breakaway chevron depicting the command position.

9. The referenced aircraft (flight leader) is obvious and easily distinguished.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
	14%	0%	0%	57%	29%
S1				X	
S2				X	
S3	X				
S4				X	
S5					X
S6				X	
S7					X

Subject	Comments
3	I got confused about which aircraft I had selected. Several times I sent incorrect commands due to the belief I had selected an aircraft other than the one that actually was selected.
4	The number # is noticeable, but some other graphic mechanism is required for redisplaying the lead besides double chevrons.

10. The text in the summary panel is legible and easy to read.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
	0%	0%	0%	57%	43%
S1				X	
S2				X	
S3				X	
S4					X
S5					X
S6				X	
S7					X

Subject	Comments
2	Would like to see UAV of interest highlighted or boxed.
4	Good displays

11. The options in the command box are logically positioned.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
	0%	0%	0%	57%	43%
S1				X	
S2				X	
S3				X	
S4					X
S5					X
S6				X	
S7					X

Subject	Comments
4	No issues. Good displays

12. The command message box terminology is plainly stated and logical.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
	0%	0%	14%	29%	57%
S1				X	
S2				X	
S3			X		
S4					X
S5					X
S6					X
S7					X

Subject	Comments
2	Some confusion on flight-wide vs. individual command.
3	I never even noticed it. Recommend some coloration/highlighting as this is important information.
4	Good displays.

13. Locating the breakaway and disconnect buttons with the cursor can be done quickly and with accuracy.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
	0%	0%	0%	100%	0%
S1				X	
S2				X	
S3				X	
S4				X	
S5				X	
S6				X	
S7				X	

Subject	Comments
1	I'm not sure how quickly I could get to either one if I had the cursor up in the opposite corner of the right display. Maybe consider a foot switch or voice command.
2	Would like to see chevrons magenta ghost for these (on display)
7	A breakaway command button would be nice on the right screen (fuel status display)

14. The rendezvous and join-up commands are logical and unambiguous.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
	0%	0%	0%	57%	43%
S1				X	
S2				X	
S3				X	
S4					X
S5					X
S6				X	
S7					X

Subject	Comments
1	The current CONOPS calls for joining to pre-contact, L (1 acft) FRT (2 acft) wings simultaneously.

15. The fuel door "open" and "close" commands are logical and unambiguous.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
	0%	0%	0%	57%	43%
S1					X
S2				X	
S3				X	
S4					X
S5					X
S6				X	
S7				X	

Subject	Comments
2	Could be more automation - on command to pre-contact - automatically open door. When leaving pre-contact for anything other than contact position, close the door.
4	The boxes are good. Found myself flying around with the doors open and forgetting to open doors to refuel. This aspect should be automated.
7	May wish to have them color coded (in the command box) to show which is active (as a backup)

16. The out-the-window display is a useful and vital feature for providing a realistic perspective of the AAR mission.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
	0%	0%	14%	14%	71%
S1					X
S2				X	
S3			X		
S4					X
S5					X
S6					X
S7					X

Subject	Comments
1	See earlier comment on question #2.
3	That depends on what kind of information you are actually getting through the pipe.
4	Nice work!

17. The level of detail in the out-the-window display is sufficient for maintaining situational awareness.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
	0%	14%	0%	43%	43%
S1				X	
S2				X	
S3		X			
S4					X
S5				X	
S6					X
S7					X

Subject	Comments
1	You probably don't need detailed ground scene, but it's nice to look at -- may be of value if refueling at low altitude.
3	You cannot actually tell whether the aircraft are co-altitude (?) unless looking from behind; in which case you cannot tell nose-to-tail. Also, how do you work collision avoidance?
5	Might be nice to have a wider FOV in the OTW display

18. The out-the-window display manipulation using the mouse is logical and easy to use.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
	0%	14%	0%	57%	29%
S1		X			
S2				X	
S3				X	
S4				X	
S5					X
S6				X	
S7					X

Subject	Comments
1	It's okay, but not what I'm used to. See comment on question #2.
4	"Hot" vehicle needs to be standard across the board.

19. The symbology and icons on the fuel status display are clear and unambiguous.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
	0%	0%	0%	57%	43%
S1				X	
S2				X	
S3				X	
S4					X
S5					X
S6				X	
S7					X

Subject	Comments
1	Several times I thought I was looking at the airplane I'd selected on the left display, but actually had another one selected.
3	I would like to get platform (?) displays for all four aircraft at the same time.
4	Color code the tanks: Green when tanks are full; yellow background when hit joker (background); red when "bingo" quantity numbers.

Open-ended Questions:

20. Are there any changes you would make to the displays that would improve the scenario?

Subject	Comments
1	We had trouble selecting a view where we could see the tanker during rendezvous.
2	Include chevron's magenta ghost for disconnect and breakaway. Nice to have a way to know or select flight-wide or individual commands. Like to highlight or outline the summary box of the UAV of interest. Incorp way (?) to box all (UAVs?) if flight wide control.
3	Change the color of the aircraft icon that is selected to indicate that it is the selected aircraft. Give an indication that the aircraft has achieved the commanded position.
4	See notes (subject's comments document)
7	In the text summary panel, it would be nice to show which UAV is highlighted (highlight the box of the selected UAV). Only way to know which UAV is selected now is if the A/R door is open. It would be nice to simply click on the UAV you want to select by clicking on that UAV's summary box.

21. What other requirements, if any, would you recommend?

Subject	Comments
2	Include an info box informing UAV controller if the Tanker or someone else has issued a command, i.e. "breakaway' or "disconnect" and also display magenta ghost showing the command
4	See notes (subject's comments document)
6	Change airspeed to calibrated.
7	It would be helpful if when the aircraft is selected on the left screen, the views on the right screen would automatically switch to the same aircraft.

22. Are there any aspects of the displays or procedures that you didn't like?

Subject	Comments
1	No. I think with operator training that it could be used as-is. Some improvements will make it even better.
2	The fuel level display not automatically changing when UAV of interest changed.
4	Need to cover all aspect of AAR. Rendezvous (1 mile trail; 2 mile trail; 1,000 ft.; Right Wing; Left Wing) AAR (Pre-contact; contact; breakaway) Post AAR (Top block; bottom block; 1 mile; 2 mile trail)
7	The screens are a bit far apart and moving back and forth between the two is a bit of a pain.

Notes of Subjects' Comments (provided during evaluation session)

Subject #1
• Pre-contact icons are hard to discriminate between the UAV and magenta outline.
• Need feedback on preclusion of moving the incorrect ship to contact point: o Example: Tiger 01 is selected, but the operator thinks that Tiger 02 in the pre-contact space is selected. Operator clicks on contact point to move Tiger 02 into place, but Tiger 01 is still select and is precluded from moving. The operator needs to know that the incorrect vehicle is selected.
• Breakaway – should be a verbal or physical (foot switch) command.
• NOTE: He failed to close the fuel door on Tiger 01. Moved Tiger 01 to observation point and proceeded to move Tiger 02 into pre-contact.
• Need an alert to prohibit an inadvertently selected ship from being moved. An undo command might be useful. (Could be text box or audio)
• Overlapping Pre-contact and Contact icons are an issue. In the contact mode, pre-contact is not visible.
• Fuel status panel – an automated switch when ships are refueled would be helpful.
• Voice feedback would be helpful – "move Tiger 03 to pre-contact". Operator has to okay command.
• OTW – really likes the display. Plenty of Situation Awareness.
• Process of selecting icons is a problem (overlapping issue).
• Need indication of active window. Highlight the header bar?
• AVDS ideas – Right mouse click changes viewing position (follows the cursor in azimuth and elevation). Left mouse click gives you eyeball view (as though you can turn your head).
• Dragging ships – have magenta line appear momentarily to indicate going to the correct position.

Subject #2
• Automate fuel door closure or provide a cue as a reminder to close it.
• Expressed concern about having a problem with a specific ship and whether just that one ship could break away (or depart the formation).
• Would like to see auto expansion of the window when a UAV falls back during breakaway. o Have display step back so you can always see the ship o Have magenta line indicate where the ship is going to make sure it's going where intended (or perhaps it could be a different color) o Provide a screen message indicating who issued the command to breakaway.
• Provide a chevron for breakaway and magenta ghost (same as other commanded positions).
• He assumed that the fuel display automatically changed when he selected a new UAV to be refueled. o He suggested that it automatically change with a newly selected UAV. If there are other systems that you want to view, only allow that display to remain up for 15-20 seconds and then have it default back to the UAV of interest.
• Didn't have a problem getting to the breakaway button, but he did indicate that it could be difficult if the cursor were in another display.
• Would like to be able to set a predefined reference point in the OTW display. Maybe a gods-eye reference behind all four so that they can all be seen together.
• Indicate which command buttons are for flight-wide commands and those that are individual ship commands. He could not distinguish merely by looking at the buttons. o Suggested using a double chevron symbol and highlighting the symbol when in flight-wide mode.
• Detail level of OTW – perhaps too much. Doesn't think it provides that much of an advantage (referred to the ground detail, would still need sky – ground contrast). o Perhaps make it selectable so when at low level you will have the detail.
• Needs idiot proofing. He could move Tiger 02 to pre-contact when Tiger 01 was still refueling. (Text box or audio alert)
• Summary boxes. Highlight the box of the selected UAV
• Have fuel display automatically switch to that UAV currently being refueled.
• Provide the ability to select where you want the ship to go during breakaway.
• Overlapping symbols a problem.

Subject #3
• If a mistake is made and you try to correct it, there's really no way to make the correction. o Suggests an Undo button
• Overlapping symbols a real problem
• He feels that most operators will want to operate the procedure much faster than is possible now. He wanted to operate simultaneously rather than sequentially.
• How do you know when the ship is actually in position (e.g., pre-contact) o Perhaps change the color of the ship or the chevron.
• Bingo and Joker fuel displayed on Fuel status
• Concerned over sending one UAV home while the rest continue refueling.

Subject #4
• Automate the fuel doors to open and close when moving to or from the pre-contact. o Idea is to automate as much as possible to off-load trivial operator tasks
• Add a cycle button (in white space at bottom). o This automatically cues all aircraft into position (e.g., 1 miles, 1,000 ft., right wing, left wing) o This button will make all decisions (fuel state, positions, etc.) For example, the ship with the least amount of fuel will be re-fueled first.
• Displays need to be a standardized (with other platforms) as possible.
• Breakaway button – keep the button depressed until it is selected again. o Idea is that the operator has control to determine if the breakaway is complete o Suggests adding pre-contact button - assumption is that the plane in breakaway will be the plane to go back into pre-contact o Add contact button (same rationale)
• OTW – the ground detail is good. The more detail, the better the SA
• Automatically have all displays provide the information of the "hot", or selected vehicle o Manually changing the displays, clicking in 3 – 4 different places, breaks down SA
• Define bubble air space (this would take the place of the chevrons) o Perhaps color code the perimeter of the space
• Entire process needs to be automated through the boom operator. o Ideally, hit the Rendezvous button and Join Right. o Does not feel there is a need to "baby sit" the fleet by manually moving the ships one by one
• Summary Panel – Have an option to collapse the four summary boxes into one formation box. o This would be good if there are multiple flights. o The operator would have the option to expand the formation (to reveal the individual ships) or collapse back to a single formation button.
• TSD – have a separate TSD for each vehicle or formation (we have this capability for the rest of the mission)
• Have drop down options on summary boxes (not command)
• Chevrons need to be a different color than green. o Perhaps purple
• Lead vehicle (tanker) should be indicated by an outline around the icon rather than double chevrons.

Subject #5
• Would prefer magenta UAV ghost to be a plain triangle to eliminate confusion.   o Looks too much like the actual UAV icon
• Breakaway button – Very important button. Should be on both screens.
• Commanded position should be indicated with a chevron, i.e., place chevron wherever the breakaway will be complete

• Fuel door buttons would be good on both displays.
  o Rather than square "buttons", have it look like an actual toggle switch.
  o Have the switch on both pages (command panel and fuel status display)
  ▪ Ghost the switch if checking the fuel of a ship that is not in the refueling stage

• Overlapping icons are confusing
• "Like it – intuitive and user friendly"

Subject #6
• Click and dragging the ship into position works best
• Overlapping icons were a problem when trying to move ships quickly
• Moved ship from observation to contact point   o need to have a message/alert to indicate this is not allowed.

Subject #7
• Add a Breakaway and disconnect button to fuel status display
• Highlight the summary box of the selected UAV.
• Asked about changing cursor size and adding mouse trails (a Window capability)

APPENDIX B

Subject Profiles

Subject #	Years AAR Exp	Type A/C Flown	# Hours per A/C
1	20	F-111	2,000+
		F-4	500+
2	12	KC-135	2000
		T-37	1000
		T-38	200
		A-320	440
		B-727	190
3	12	FA-18	2000+
		T-2	950
4	6	T37	100
		T38	100
		KC-135R	1200
		RQ4A	500
		X-45A	50
		C12	30
5	14	F-14	1700
		F/A-18	200
		F-16	500
6	20	A-7 D/K	2100
		F-16 C/D	1000
7	2.5	KC-135R	650